

Iterated Learning with Human Subjects: Adding Communication and Feedback

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Declaration:

I have read and understood The University of Edinburgh guidelines on plagiarism and declare that this written dissertation is all my own work except where I indicate otherwise by proper use of quotes and references

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Abstract

The framework pioneered by Cornish (2006) and Kirby, Cornish and Smith (2008) has opened a new door for language research with human participants in a laboratory. They were able to show that a compositional and expressive language could emerge with no intentional design on behalf of the subject. However, filtering for homonymy was necessary to produce a language that adapted to be learnable by becoming more structured and expressive. What I proposed was to introduce communication and feedback to investigate whether these factors would act as a selection pressure on the language to become not just structured but expressive, without the need to artificially filter for homonymy. My results suggested that communication on its own is not enough of a pressure to produce an expressive language but when feedback is introduced, a compositional and expressive language emerges.

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Contents

Declaration	2
Abstract	3
Acknowledgments	4
Chapter 1 Introduction	7
1.1 Cultural Transmission	8
1.2 Roadmap	9
Chapter 2 Background	10
2.1 Language Evolution Background	10
2.2 Cultural Evolution and Transmission	11
2.3 The ILM	15
2.3.1 Computer Modelling	13
2.3.2 What is the ILM?	15
2.3.3 Experimental Studies of Communication	16
2.3.4 Artificial Language Learning Experiments	17
2.3.5 Experiments with humans	17
2.3.6 Experiments with primates	19
2.4 Recent Studies in Language Emergence	22

2.4.1	Human Iterated Model	23
2.4.2	My aim	24
2.5	Iterated Learning with Human Experiments	25
2.5.1	Structure of the Meaning Space	26
2.5.2	Structure of the Initial Alien Language	27
2.5.3	Participants	27
Chapter 3	Experiment 1	28
3.1	Methodology	28
3.2	Results	30
3.3	Discussion	35
Chapter 4	Experiment 2	37
4.1	Methodology	37
4.2	Results	37
4.3	Discussion	42
Chapter 5	Discussion of Experiments and Results	43
5.1	Issues with Experiment	43
5.2	Discussion of Experimental Design and Results	44
5.3	Implications of Results	45
Chapter 6	Conclusion	49
Appendices		51
References		58

Chapter 1:

Introduction

As one of the defining features of our species, the importance of language in our every day lives cannot be underestimated. We are who we are as a species because of our ability for language but why is language the way it is? Why is language not different? To answer this, language researchers have to look at the evolution of language in our species but to do this they have to tackle the problem of studying something that cannot be seen and leaves no fossils (Hauser and Fitch, 2003). Although the languages that are spoken today and the languages that we have been able to reconstruct (e.g. proto-European) are evidence of language evolution, these are only the results of language evolution so far and can only give us limited insight into how language evolved to its current state. Kirby and Hurford (2002) suggest that “language emerges at the intersection of three complex adaptive systems” (Kirby and Hurford, 2002: 122), these are learning, cultural evolution and biological evolution.

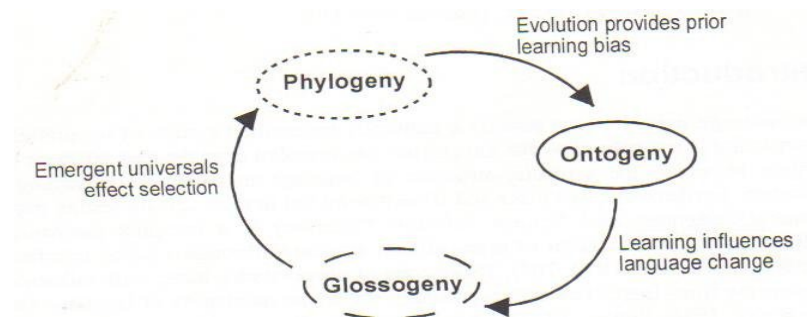


Figure 1: The three adaptive systems that give rise to language with interactions illustrated. Taken from Kirby and Hurford (2002) with permission.

Ontogeny represents the learning system where children react to the linguistic environment around them and adjust their own linguistic knowledge to both understand and be understood by those around them. Cultural evolution is represented by glossogeny in the illustration as over time languages change in vocabulary, semantics and syntax.

Phylogeny describes the biological evolution that described how the biological processes for our ability for language adapt to different pressures in the environment. What makes this approach to language evolution so difficult is the number of complex systems involved and our knowledge of how these systems interact is rather limited (Kirby and Hurford, 2002). Additionally, how can and how should this approach be best studied?

1.1 Cultural Transmission

The study of language evolution has, in recent years, proposed that cultural evolution can help explain the evolution of the processes involved in and the structure of language (Ellefson and Christiansen, 2000, Kirby and Hurford, 2002). Language evolves by cultural evolution by being passed on from generation to generation by a process called cultural transmission. Cavalli-Sforza and Feldman (1981) argue that something that can be defined by ‘cultural’ is any trait that is learned by non-genetic transmission. Non-genetic transmission includes conditioning, imprinting, imitation, teaching and observation.

Language is one such trait and is learned by “observing the linguistic actions of others” (Cornish, 2006: 3). As language is learnt by observing the language of others, the output of one person becomes the input for others who in turn produce the input for the next generation of language learners. This form of learning is known by cultural evolutionists as iterated learning (Kirby and Hurford, 2002 , Christiansen, 2000)The study of language evolution by cultural transmission has traditionally been facilitated by computer modelling which has allowed us an insight into the emergence of language without replicating biological evolution (Kirby et al, 2008) However, computer modelling is, by necessity, simplistic and not very reflective of how human populations would act. To be able to investigate whether or not these computer models are reflective of human populations and if their results can be applied to the emergence of language and its properties in our species, experiments on humans need to be carried out. To do this cultural linguists have developed a framework by which constraints and pressures on language emergence by cultural transmission can be investigated using human participants in a controlled laboratory environment. This framework is the Iterated Learning Model and will be the focus of my study.

Language must be learnable to survive to the next generation “certain hallmarks of language are adaptive in the context of cultural transmission; that is languages themselves adapt to survive by adapting to be learnable” (Brighton, Smith and Kirby, 2005: 292).

Previous research (Kirby et al, 2008) has shown that language adapts to become more learnable to survive transmission between generations. However, unless the data is artificially filtered for homonymy between iterations (between each generation) in Kirby et al’s (2008) study the language will adapt to survive the transmission by becoming structured but underspecified. What I aim to do in this paper is to investigate whether communication and feedback in an ILM is enough to create a pressure for an adapting language to become not only structured but expressive.

1.2 Road map

In this study I will adapt Cornish (2006) and Kirby et al’s (2008) cumulative cultural evolution experiment to include first communication (with no feedback) and then communication with feedback to observe if a selection pressure for expressivity emerges. I shall provide a background to the topic of cultural evolution and transmission in Chapter 2 with examples of the findings of computational modelling and experimental design. In Chapters 3 and 4 I will outline my experiments and their results and in Chapter 5 I will discuss the implications of my findings and suggestions for further research. I will conclude my study in Chapter 6

Chapter 2:

Background

What is that makes humans so unique? What trait do humans have that we can consider ourselves different from other animals? Smith and Kirby (2008) isolate two such features of our species that they argue are central to our distinctiveness: the complexity of our culture and the even greater complexity of our system of communication. Although culture is not unique to our species the complexity of our culture and its role in the evolution of our species should not be underestimated. Language is something that only our species possesses. Other animals including birds (Gentner et al., 2006), dolphins (Herman et al., 1984) and our ape cousins (Savage-Rumbaugh & Lewin, 1994) have been shown to possess degrees of linguistic-like ability but it is very basic and these animals still only possess communication and not full language.

Smith and Kirby (2008) argue “that the co-occurrence of these two properties [culture and language] is not coincidental”. (Smith and Kirby, 2008: 3594). The importance of culture will be explained in more detail later in section 2.2 but for now I will give a brief history of the study of the origins and evolution of language.

2.1 Language evolution background

Humans have been attempting to explain the phenomenon of language for as long as we have been trying to explain our own existence. The link between our ability for language and what defines us as a species is so important that attempts to explain language appears in creation myths from around the world e.g. the Tower of Babel in the Old Testament. The scientific community were not, by the time the topic was banned by

the linguistic society of Paris (*Société de Linguistique de Paris*) in 1866 (Christiansen and Kirby, 2003) in a better position to explain the origins and evolution of language than the creation myths so the topic in the most part was abandoned for over a century resulting in the ban. Advances in technology and our understanding of how the human body and mind works meant that when Pinker and Bloom published 'Natural language and Natural selection' in 1990, the topic of language emergence was, for the first time, scientifically researchable. At the time of the publication of this landmark paper, the main theory concerning our capability for language was Universal Grammar theory as developed by theoretical linguists such as Noam Chomsky (1965) in the mid twentieth century. Universal Grammar theory proposes that all languages share a common set or rules of structure and that these rules are stored in the human brain in an innate language acquisition device (LAD), a kind of language organ that is as much a part of us as our heart or lungs. Chomsky (1965) argues that the basic set of rules that the LAD contains result in language universals.

This theory of an evolved innate grammar is proposed by the LAD evolving through natural selection possibly for "an innate specialisation to code increasingly complex propositional information" (Christiansen and Kirby, 2003: 302). There are competing theories as to why such a complex trait would be selected for from an increasing need to store information about complex social interactions in our evolving species or to replace grooming in an increasing population to help build and strengthen social connections (Dunbar, 1997). Overall, these theories propose that the complexity of syntax is due to some 'complex design' and can only be explained by biological evolution (Christiansen and Kirby, 2003).

2.2 Cultural evolution and transmission

Universal grammar theory and biological adaptation of language are not universally accepted however with alternative theories arguing not that our brain evolved around language, as is the claim of universal grammar, but rather language evolved to fit the cognitive constraints of the brain (Ellefson and Christiansen, 2000). Ellefson and Christiansen (2000) argue that a language universal such as constraints on elements moving between boundaries are not due to an innate universal grammar but to the

limitations of the human brain in regards to sequential learning and that “many language universals may reflect non-linguistic, cognitive constraints on learning and processing of sequential structure rather than innate UG” (Ellefson and Christiansen, 2000:1). If language has had to shape itself around our brain and cognitive processes then how are we to explain the evolution of language which is not a physical trait? Although biological evolution plays its part in the evolution of language we must “take into account that biological selection is only one of the complex adaptive systems at work”. (Kirby and Hurford, 2002:122). A solution to this problem is cultural evolution. Cavalli-Sforza and Faldman (1981) argue that cultural evolution can be used to describe traits that are learned by imprinting, conditioning, observation, imitation or from teaching – in other words by non-genetic transmission. Even Darwin touched upon the nature of language learning and the importance of how it is transmitted “I cannot doubt that language owes its origins to the imitations and modification...[of] man’s own distinctive cries” (Darwin, 1872). Proponents of the cultural evolution of language (Kirby and Hurford, 2002, Christiansen et al., 2002, Smith and Kirby, 2008) argue that language structure can be explained by the process of cultural transmission. Cultural transmission of language is when a language is transmitted from one generation to the next through a bottleneck. . The bottleneck is the proportion of the language that the next generation is exposed to when learning the language. It is essential for the structure of a language for the structure to be learnable. This is because when it is being transmitted from one generation to the next, like the adults and learners in the simulation, it is passing through the bottleneck of the child’s (learner’s) mind and it is limited by the mind’s capabilities, “The structure of a language is under intense selection because in its reproduction from generation to generation it must pass through a narrow bottleneck: children’s minds” (Deacon, 1997: 110).

To become more learnable a structure can do one of two things:

- 1.) Become generalisable. Human language does this by the structure being compositional. This is when the meaning of the whole is composed of the meaning of its constituent parts and the way they are put together.

2.) The second way is to make sure the structure is used often enough to survive the bottleneck. This can be seen in the top ten most regular verbs in English being irregular. Because of the frequency of these words their irregular structure is not a problem for a child to remember, after they have had enough exposure. If there are no bottlenecks present in the simulation, neither compositionality nor a high frequency of irregular structures emerge. If there is too much of a bottleneck the language will not be transmitted stably.

“Cultural transmission mechanisms play a central role in explaining the emergence of certain types of linguistic structure – creating selection pressures for language itself to evolve to become learnable by its human users” (Cornish, 2006: 8)

2.3 The ILM

2.3.1 Computer Modelling

Computer models have facilitated the research into language evolution by allowing researchers to investigate issues that may have affected the evolution of language. As there are a great number of different factors that may have had an influence in the evolution of language, computer models allow us to consider several processes and their influences at the same time (Christiansen and Kirby, 2003).

Computer modelling in researching the evolution of language can be divided into three categories:

- 1.) Evaluation: Computer models allow researchers to discover unforeseen problems.
- 2.) Exploration: Computer models allow us to view how explanatory mechanisms or theoretical constructs interact. This can help researcher produce new theories based on the results.
- 3.) Exemplification: An explanation can be demonstrated by using computer models. (Christiansen and Kirby, 2003).

For the aims of this paper I shall be concentrating on the vertical models of iterated learning. However it is worth mentioning horizontal modelling.

Kirby's (1999b, 2002a) models used the most simple language transmission model in a vertical diffusion train and have been very important in the development of iterated learning models using humans. Kirby's (2002a) model consists of an 'adult' agent and a 'child' agent in each iteration. Once the child becomes the adult, the original adult is removed a new child is introduced. This extremely simplified population model was intended to allow the model to concentrate on the evolution of syntax. What these models showed us is that biological evolution was not needed for the development of structured languages. Kirby, (2002)

Batali (1998, 2002) are examples of horizontal transmission models that are modelled symbolically and with neural networks where within a population behaviour is learned from companion agents and all agents are present during the experiment. The two bottlenecks that are in attendance here are a training bottleneck and a memory bottleneck. The training bottleneck requires generalisations from a finite input and the memory bottleneck results in the gradual decay of unused representations (Line, 2010). The results of these bottlenecks are similar to the transmission bottlenecks that occur in vertical transmission models such as Kirby (2000) even though the models differ in organization. This would suggest that these elements play a role in the emergence of syntax (Pippa, 2010). This is supported by findings of other models which show that when horizontal in vertical transmission take place together, structured and table languages emerge but when the horizontal transmission element is taken out of the model, the language emerges to be unnecessarily intricate. (Swarup, 2009)

Computer modelling does not stand on its own as a research tool. Computer modelling had previously been used in conjunction with data collection, mathematical modelling and experiments (Christiansen and Kirby, 2003). The computer models that we are interested in are those that relate to language evolution by cultural transmission and that have already shown that cultural transmission can autonomously explain the development of certain features that are universal in language such as syntax (Kirby, 2000) [see Hannah's] and regularity (Kirby, 2001). It is the findings from simulations such as these that inspired the original framework for the human ILM which I will describe below.

Until recently computer modelling has been the main way to investigate “how various types of hypothesised constraints may affect the evolution of language” (Christiansen et al, 2002: 144). The computer models allow us an insight into the emergence of language without replicating biological evolution. To explain this Kirby and Hurford (2002) present the Iterated Learning Model (ILM) which they describe as “a general approach to exploring the transmission over a glossogenetic time scale of observationally learned behaviour” (Kirby and Hurford, 2002: 123). Language is learnt by observing the linguistic actions of those around them (Kirby et al, 2008).

2.1 What is the ILM?

The idea behind the ILM is to model how language exists and continues via its two forms:

I-Language – the internal representation of language

E-Language – the external representation of language (the utterances people make).

For any language to persist, that language has to be mapped, through use, from I-language to E-Language and again from E-language to I-language which happens through the learning process. Only when both of these mappings occur can a language survive between generations. This is what is known as the bottleneck that a language has to pass through when being transmitted from adult to child (or more accurately from an adult to the child’s mind).

What Kirby and Hurford (2002) are exceptionally interested in is the mappings between E-language and I-language as these mappings between meanings and signals are subject to this bottleneck. To be able to model these mappings the ILM is composed of the following four components: a meaning space, a signal space, one or more language learning agents and one or more language using adult agents (Kirby and Hurford, 2002). Each iteration of an ILM involves giving a random set of meanings to an adult agent for which they have to produce signals. The meaning-signal pairs that the adult agent produces are then used as the input (E-language) with which to train the learning (child) agent or agents. After a period of learning, also known as the critical period (Kirby and Hurford, 2002), the child agents form their own I-language and are excelled to adult

status. Once the learners become adults, the old adults are removed from the model and new learners are introduced – preserving the population size. Kirby and Hurford (2002) stress that this is a very simplified population dynamic and that more complicated approaches are possible but for what we are expecting of the ILM this simplified approach is acceptable. This is repeated thousands of times or until a stable point is reached. The ILM does not start with a linguistic system – the first adults have no I-language and no E-language exists at the beginning of the model, it has to be created by the adults.

2.2 Experimental studies of Communication

There are naturally occurring instances of the cultural evolution of language that can be observed on a realistic timescale for instance the emergence of new sign languages such as the Nicaraguan sign language. The Nicaraguan sign language is a sign language that emerged from the late 1970s when a school was opened for the deaf children in the community. As there has previously been no centre for the education of deaf children there none of the deaf children used an established sign language but relied mostly on home signs that they had developed between individually between them and their families (Senghas and Coppols, 2001). However, once the children went to school (which initially forbade the use of signs and no alternative sign language was taught) the children developed a pidgin sign language between themselves that very quickly, within a decade, developed to a more expressive and complex creole sign language (Senghas and Coppols, 2001). The existence of Nicaraguan sign language has allowed linguists to witness and study the birth and development of a new language in a way that has never been possible before. However, the study of this new language is limited to observation as due to its natural circumstances, potential influencing factors cannot be isolated and manipulated to determine their individual (or interacting) effects on language evolution. The study of the cultural evolution of language in a controlled experimental environment has been difficult and, until recently, limited. Traditionally the only way to do this has been computer simulations to allow the study of the effects of different processes, environments and learning biases that may be important.

Computer simulations are useful and they can help us understand how different aspects of human communication could have evolved through cultural evolution. We are not however computers and the simulations do have their limits and criticisms. Part of computer modelings' strongest points is being able to separate biological evolution from cultural evolution to allow research into factors of cultural evolution that may affect language evolution. However, unnatural starting conditions are necessary for computer models to work and this is obviously not how human populations work (Scott-Phillips and Kirby, in press). Because we want to know about human language and human cultural evolution we should therefore extend our research to human participants.

In the last few years this is exactly what has been done with human participants in a laboratory with the intention of observing emerging symbolic communication systems in a controlled environment. I will now review some of the recent experiments in human communication.

2.3 Artificial Language Learning experiments

The artificial language learning paradigm (ALL) is a technique used for researching human and non-human language acquisition and statistical learning abilities. For ALL, you create a small artificial language with specified structural properties dependant on what you want to investigate. The language is then taught to participants, human or otherwise, and then they are tested on the language to see what they have learnt/acquired. (Cornish, 2006).

2.3.5 Experiments with humans

Christensen (2000) suggested that ALL can be used to study the cultural evolution of language using human participants in a laboratory environment. As previously mentioned, it is believed that certain universals, e.g. word ordering, are due to the restrictions of human sequential learning and processing constraints (Ellefson and Christensen, 2000). Christensen et al. (2002) created two artificial languages, one of which had a consistent head of phrase position and the other was inconsistent with respect to the phrase's head position. The computational model for this had predicted that head order inconsistent languages are not naturally found because they are simply too

hard to learn. Christiansen et al's (2002) ALL experiment confirmed this as participants performing significantly worse on the inconsistent languages.

ALL studies have been used to investigate Creole formation/creation. A creole is a contact language that develops when speakers have a need to communicate but do not speak a common language. An historically common environment for creoles was on slave plantations where slaves were often deliberately placed with other slaves who spoke different languages to try to avoid rebellion. Related to the investigation of creoles, Hudson-Kam and Newport (2005) used ALL to investigate the roles of adults and children in the formation and development of creoles specifically regularisation. What they were interested in was how languages with irregular variation (as is often seen in early creole formation) develop to become regular. This is an example of languages becoming more learnable as predictable variation is, not surprisingly, easier to learn than unpredictable variation.

Their study consisted of two artificial languages, one of which had a constant determiner in the noun phrase and the other language only had a determiner present 60% of the time. These two languages were then taught to adults and children (aged 5-7 years old) who were participating in the experiment. Hudson-Kam and Newport (2005) then tested the participants for grammaticality judgements and production data. For the group which had a determiner 100% of the time, there was no significant difference in performance between adults and children. For the language with the inconsistent determiner children, but not adults, regularised the language usually by always using a determiner or not using one at all Hudson-Kam and Newport (2005). What the children were doing was creating consistency in the language. Adults however, did not reproduce the inconsistency in the input. This suggests, according to Hudson-Kam and Newport (2005) that children are extremely important for the formation and development of new languages and they regularise and stabilise the grammar of an emerging language. This supports the vertical transmission from adult to child that we see in ILM. The bottleneck is imposed by the child who needs to learn the language rather than the adult who produces it. Cornish (2006) points out however, that the ILM does not stipulate that the learner has to be a child, as long as the learner has had little or no previous input from the

stimuli. This is an important fact as many, if not most, of the research done in this area involves adult participants.

2.3.6 Experiments with primates

Although we are interested in the cultural transmission of human language, social learning in primates can help us understand the learning processes in human cultural evolution.

There are two types of observational learning; imitation and emulation. Imitation is when something is learnt by watching it being done by another. Emulating is achieving the same end result but not necessarily achieving the goal in the same way that was observed.

To study and try to distinguish between learning by imitation and learning by emulation Whiten et al. (2005) carried out experiments with chimpanzees. Three groups of chimpanzees in captivity were used in the experiment, where the chimpanzees were introduced to a new tool and each of the three groups were presented with a new food retrieval task. In two of the groups a high ranking female was taught how to retrieve food from 'pan-pipes' by poking it with a stick or lifting a latch with a stick. In the third group there was no one-on-one training provided so that the third group could act as the control group. The non-control groups observed their instructed female obtaining food by using the new tool and method taught to her for a period of a week without the rest of the group being able to access the pan-pipes. After the week of observation the rest of the two groups were able to access the task for ten days. Out of the 32 chimpanzees in the two non-control groups, 30 completed the task the same way their taught female had – the group 'norm', with only a few discovering the alternative technique by themselves. As with human studies, Whiten et al. (2005) "found evidence of a conformist bias...as a powerful tendency to discount personal experience in favour of adopting perceived community norms" (Whiten et al., 2005:738). In the control group none of the chimpanzees were able to complete the task and obtain food despite the group's intense interest.

What Whiten et al. (2005) were looking for was the way that the different techniques (poking with a stick or lifting a latch with a stick) would spread to the rest of

the troop either by imitation or emulation. This is not the same as the direction of the Iterated Learning Model as this way transmits through a group and not on a one-to-one basis. This is relevant, or at least useful, for what we are interested in as it gives us an insight to the learning of our closest cousins, quite likely our shared ancestors and possibly our own society, in a controlled but more natural environment than a laboratory.

Garrod et al. (2007) ran an experiment to “investigate the communicative origins of graphical symbols” (Garrod et al, 2007: 983). Using a picture drawing game (pictionary game) where participants had to produce pictures to represent concepts or match said pictures to a concept, Garrod et al, (2007) were able to demonstrate how feedback can affect the evolution of iconic symbols that resemble, to a degree, what they represent to graphical symbols that are dependant on prior knowledge of how the sign related to its object. When there was no feedback (when the participant was producing drawings for a partner that they only thought existed) the drawings that the participant produced were complex and iconic throughout the experiment. When there were two participants and minimal feedback the drawings that the ‘director’ (drawer) produced became cumulatively simpler and more symbolic in nature. When the participants were under the condition of being able to take turns as the director and matcher the communication became more efficient. Garrod et al.’s (2007) study also showed the quality and quantity of feedback that is allowed. This relates to my own study as it highlights the importance of feedback in the evolution of language (this experiment is just a reflection of written language) as the language is becoming more learnable – which is necessary for the survival of any language. Garrod et al. (2007) also argue that as there is no transition from iconic to symbolic in the non-interactive condition that supplied no feedback, it is unlikely “that the move from iconic to symbolic graphical representations could evolve rapidly without this kind of interaction” (Garrod et al, 2007:983).

Computational modelling has also highlighted three features of human learning that are central and essential for linguistic structure to develop. These are: the ability to generalise, a bias against homonymy and a bias against synonymy (Brighton, Smith and Kirby, 2005). These result suggest that language could only have evolved to its present state because we have such biases.

Walker et al. (2009) suggest two factors that may play a role in explaining the evolution of language: learning biases and social collaboration. Learning biases play an important role in the Iterated Learning Model. Due to the nature of how a language spreads to a population, by learning and observing others' behaviour, learning biases can affect what gets transmitted and what does not, influencing language's evolution as a language has to be learnable to survive, "languages that are hard for humans to learn simply die out, or more likely, do not come into existence at all" (Christiansen et al, 2005:5). Although it is the learning biases that we are more interested in it is worth to mention the role of social collaboration as this is linked to the feedback aspect of my study.

Walker et al. (2009) developed an experiment, based on Garrod et al's (2007) experiment reviewed above, that was able to isolate collaboration and learning biases in the evolution of novel ways to communicate. They did this to investigate the roles that social collaboration and learning biases play in the emergence and evolution of languages. What they aimed to do was determine which (or both) of these qualities is necessary for language evolution.

Their study consisted of two conditions: one that allowed the participants to collaborate (the interactive condition) and the other where the participant was under the impression that they were interacting with another person but were not (known as the pseudo-interactive condition).

In the interactive condition, two participants would take turns as 'directors' or 'matchers' where one had to draw, via a computer, a concept and the other, on another computer, had to choose a concept that they believe matched the drawing. Interaction between the participants was encouraged with both participants being able to see what the other had drawn while it was being drawn (or annotated by the matcher for clarification) although feedback was not supplied for the final success of the communication.

In the pseudo-interactive condition the participant was under the impression that they were in the same situation as described but in reality were not competing with a partner. When they were the director they would draw the concept but would have no interaction with anyone as there was nobody to match the corresponding concept. The participant was then shown pictures that were produced by participants in experiment one to which

they had to match a concept. No feedback was given in the way of the pseudo-partner reusing the participant's drawing which was a degree of feedback for those in the interactive situation. Again there was no interaction with the pseudo-partner and they could not annotate the pictures for clarification. The results of the experiment were that the interactive condition resulted in a greater rate of identification of pictures, more refinement of the pictures and shared concepts of the signs used. The pseudo-interactive condition did not produce any graphical alignment (shared use of images for certain signs). This let Walker et al. (2009) to suggest that collaboration plays a large role in the evolution of shared communication systems.

Walker et al (2009) acknowledge that learning biases do still have their role in language evolution but argue that their role is not as great as originally thought. This is relevant to the ILM as learning biases play a large role in the ILM but does not have any social collaboration. Walker et al. (2009) suggest that social collaboration and learning biases may be working simultaneously in language evolution but are influencing different things and are best used to study lexical evolution and the evolution of language structure respectively.

This study is very relevant to my own investigation as it is not just isolating social collaboration from learning biases but also the element of feedback which I intend to do.

2.4 Recent study of language emergence

At the time of Cornish's (2006) study, there was, in her own words "still not a proper frame work within which to examine how more complex cultural traits (such as language) emerge and are culturally transmitted" (Cornish, 2006 :15). Cornish's (2006) study was, in her own words "initially rather modest" (Cornish, 2006: 39) however, it was in reality a benchmark paper, setting the standard for future investigations into cultural transmission and the evolution of language (Line, 2009). What Cornish (2006) set out to do was to create an ILM using different aspects of ALL to create a flexible framework that would allow the study of different modes of cultural transmission such as has been discussed e.g. horizontal and vertical transmission. It is this study that I intend to replicate but with a minor adjustment.

2.4.1 Human Iterated Learning Model

What Cornish did was create an experiment where participants were trained on a subset of an unstructured ‘alien’ language consisting of 27 individual pictures (different coloured shapes with associated movements) and strings of created words. They were then tested on the subset and on some of the language that they hadn’t been tested on (a fact the participants were not aware of) to see if they would generalise to the unseen items of the language. The participant’s output would then become the input data for the next generation. In the first experiment a more structured language emerged however it was not descriptive enough as multiple related words (e.g. meanings with the same shape, colour or movement) ended up with the same signal. For the second experiment Cornish (2006) filtered for this homonymy between each iteration. Over the space of ten iterations (referred to in Cornish’s (2006) experiment as generations) a compositional language emerged. This has inspired further research (Line, 2010) who adapted this framework for horizontal transmission.

Line (2010) set out to investigate the effects of horizontal transmission on the Human Iterate Learning Model experiment framework as the large part of the research done using this framework has concentrated on vertical transmission, for example Kirby et al. (2008). To do this Line (2010) added a “novel dyadic methodology” (Line, 2010: 59) to the framework of Kirby et al. (2008) where participants were trained on an alien language and then tested on it. The participants did not know that there was another participant being trained and tested on the same data. After each round a random selection of each participants’ output would become the input for the next round of training for the other participant (unknown to the participants as they were not aware of each other’s presence.). Line (2010) refers to each set of training, testing and swapping data as rounds rather than generations as the language is never transmitted to new untrained participants as happens in vertical transmission where they are simulating the transfer of language from one generation of speakers (adults) to a new generation of learners (children). Line’s (2010) results showed that over the rounds a structured, learnable and expressive language emerged without the need of filtering for homonymy that has been necessary in previous research – see the description of Kirby et al.(2008) below. Line (2010) argues that her results suggest that horizontal transmission “plays a

key role in the establishment of a shared language within a community, as apposed to the more blood-line linked vertical transmission” (Line, 2010: 59).

2.4.2 My Aim

What I intend to do is to re-run Kirby et al’s(2008) experiment (also Cornish, 2006) but I will not be filtering for homonymy between generations to produce a compositional and expressive language. This is because I hypothesis that by adding communications, firstly perceived communication without feedback then communication with feedback, a structured and expressive language will emerge. The reasoning behind this is to tackle the artificiality of the ambiguity filtering in Kirby et al’s (2008) study which is acknowledged in the study as artificial but suggested it to be similar to the pressure that is places on languages to be expressive that would arise “from communicative need in the case of real language transmission” (Kirby et al. 2008: 10684). What I hope to achieve is to investigate what creates the pressures for expressivity. Scott-Phillips and Kirby (in press) highlight that as yet “these two different aspects [communication and feedback] have been studied together, but it might be the case that one or the other is driving the results observed so far” (Scott-Phillips and Kirby, in press). The experiments that I propose to run allow me to isolate the results of communication and feedback to investigate which or both of these creates a pressure for expressivity.

However, by defining the choices in this way it did encourage mistakes to be interpreted by misinterpretation of component parts of a string as the speaker can interpret the mistake in terms on colour shape or aspect. This may directly encourage the original interpretation of the input language in terms of three referent components and although I would argue that its influence is minimal and actually less than the effect of the design of the meaning space itself. It is however worth noting the potential influence of this and it may be worthwhile to rerun the experiment with the three alternative meaning choices being chosen along the terms of the alternative idea (one seen, one unseen, one random) to determine the influence (or otherwise) of the chosen alternative meaning choices.

2.5 Iterated learning with human experiments.

As previously mentioned my experiment will be an adaptation of Kirby et al's (2008) experiment. Kirby et al's (2008) experiment set out to validate that their framework could support previous suggestions from computer modelling that cultural transmission can explain the emergence of language features such as syntax or regularity (Kirby, 2000, 2001) on its own and without intentional design on the part of the subject. To do this they carried out an experiment using human participants which was then run computer. Over three rounds the participants were trained on an 'alien' language consisting of meanings (pictures) and signals (strings of words) and then tested on the language. The testing consisted of asking the subject to reproduce the signal for the meaning being tested. The participant's output from the last round of testing was then used as the input for the next generation. There was no previous training on the language and the participants got no feedback throughout the experiment and therefore "each person must discover the language anew based on solely on the observed behaviours of the previous generation" (Cornish, 2006: 16). Kirby et al's (2008) results showed that over time (ten generations) that through cultural transmission language adapts to become more learnable. However, the initial way that language did this in Kirby et al's (2008) experiment was to become structured but underspecified. For example, in one of her diffusion chains by the end of the experiment (by the 10th generation) all shapes and colour combinations with a straight movement had one signal, all meanings with a circular movement had one signal and the meanings with an up and down movement were distinguished only by shape (one word for all up and down squares, one for up and down triangles and another for all up and down circles).

To combat this, Kirby et al. (2008) artificially filtered for ambiguity between each generation allowing only one meaning to be paired with a signal for the input of each generation's input so that "underspecification is an evolutionary dead-end" (Kirby et al, 2008: 10684). This resulted in a compositional and expressive language. For the most part a morpheme-style structure emerged with separate morphemes for shape, colour and movement.

→	n-ere-ki n-ehe-ki n-eke-ki	l-ere-ki l-aho-ki l-ake-ki	renana r-ene-ki r-ahe-ki	□ ○ △
↗	n-ere-plo n-eho-plo n-eki-plo	l-ane-plo l-aho-plo l-aki-plo	r-e-plo r-eho-plo r-aho-plo	□ ○ △
↻	n-e-pilu n-eho-pilu n-eki-pilu	l-ane-pilu l-aho-pilu l-aki-pilu	r-e-pilu r-eho-pilu r-aho-pilu	□ ○ △

Figure 2: An example of the expressive and compositional language that emerged via cultural transmission. (Taken from Kirby et al (2008) with permission).

However, Kirby et al (2008) acknowledged the artificiality of this filtering but claims that it is “an analogue of a pressure to be expressive that would come from communicative need in the case of real language transmission” (Kirby, Cornish and Smith, 2008:10684). Therefore, to this framework I will be adding communication and then communication with feedback with the expectation that one of these conditions will create a pressure for language to adapt to be learnable by becoming structured and expressive without the need to artificially filter for homonymy.

2.5.1 Structure of the meaning space

The meanings in Kirby et al’s (2008) language were made up of three simple geometric shapes with three different colours and with three different associated movements. There were 27 of these (all possible combinations of colours shapes and movements were used). I shall be using the same meanings for my own experiment.

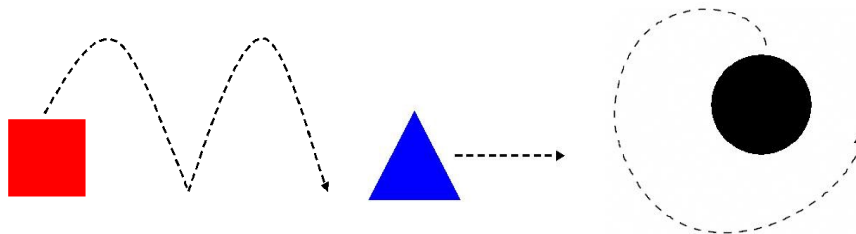


Figure 3: Example of meaning space

2.5.2 Structure of the initial alien language

For the first generation's input (the strings needed for the signals) Kirby et al (2008) constructed a completely random language consisting of nine syllables selected from a set of forty syllables which were then concatenated (with replacement) to create strings ranging from 2 to 4 syllables in length. Each string was then randomly paired with one of the 27 meanings. Cornish's (2006) reasoning behind this was that this random signal-meaning pairing is not dissimilar to how creole languages emerge from the more simplistic pidgin languages. As pidgins are not people's mother tongue and are a mishmash of structure and vocabulary of different languages that come in contact with each other yet creoles develop from pidgins yet their essential structure is almost unrecognisable from the original pidgin. Cornish also argues that by starting off with such an arbitrary and unstructured language that it should "make it harder for subjects to find structure upon which to build a language not easier" (Cornish, 2006: 18). The languages produced were all structured CVCV (consonant, vowel, consonant, vowel).

2.5.3 Participants

All participants were monolingual English speakers. This was decided upon to eliminate the effect of the advantages that bilingual speakers have over monolinguals in learning novel words (Marian et al, 2009). All participants were also university students ranging from 19 years of age to 34 years of age.

Chapter 3:

Experiment 1

3.1 Methodology

The experiment consisted of ten generations of one participant per generation (iteration) and was conducted on a computer. Each generation consisted of a short practise round and three main rounds consisting of training and testing as described below. The practise round was to allow the participant to get to terms with the training and testing procedure. The language used here consisted of 27 meaning-signal pairs that were assigned, at random, into one of two categories SEEN and UNSEEN with the SEEN set containing 14 meaning-signal pairs and the UNSEEN set containing 13 signal-meaning pairs. The meaning-signal pairs consisted of a picture and a string of letters respectively. Participants were asked to always give a signal so that their ‘partner’ could make a choice.

Practice Round:

Training:

The participant is shown 4 meaning signal pairs that do not appear in the experiment (a yellow diamond with an upwards movement, a green octagon with a 180degree movement, a purple hexagon with an upwards movement and a purple diamond with a 180 degrees movement (see appendix 4 for the shapes) and four related strings that do not appear in the initial alien language for generation 1.

Round 1 and 2:

Training:

The participant is tested of 7 of the SEEN set chosen at random. Each meaning-signal pair is shown twice in a random order. The participant is under the impression that their ‘partner’ in the other room is being trained on the same data

Testing:

The participant is then tested on 14 of the meanings. They are shown the meaning on the screen and asked to type in the corresponding signal as best as they can remember it. The meanings that they are tested on consist of the 7 from the SEEN set that they were trained on and 7 meanings from the UNSEEN set that they have not been trained on.

Round 3

Training:

The participant is tested of 7 of the SEEN set chosen at random. Each meaning-signal pair is shown twice in a random order. The participant is under the impression that their ‘partner’ in the other room is being trained on the same data

Testing:

The participant is tested on all 27 meanings and their output from this round becomes the input for the next generation.

When the participant is trained the string appears on the screen for one second then the signal and meaning appear together on the screen for a further five seconds. The next training item appears after a one second blank screen. Once the participant has seen each shape twice they are allowed an optional break and are allowed to continue when they choose. Before the participant begins they are told that they are working with a partner who is already set up in the next booth and will be trained on the same data. They are told that when they are tested on the meanings they will be asked to type in the corresponding string so that their ‘partner’ can chose from a selection of four meanings the one they think the participant (the ‘speaker’) has described. To help the ‘speaker’ the

three additional choices that their partner' will see are shown at the top of the screen during each meaning testing. The three additional meanings differ only by one aspect to the target meaning. For example, if the target meaning was a blue triangle with a straight movement three alternatives could be a red triangle with a straight movement, a blue square with a straight movement and a blue triangle with a circular movement. Once the 'speaker' has typed in the signal there is a ten second pause and a message reading "please wait ten seconds while your partner makes their choice". As there was no 'partner' no feedback was given and after the ten seconds the next meaning to be tested is displayed. Both verbal and written instructions were given to the participants and they were asked to always give a response even if they were unsure of the 'correct' answer. For a copy of the written instructions please see appendix 3. The participants were not told about the aim of the experiment or that their responses would become the training data for the next generation until after the experiment.

Throughout the experiment the participant is under the impression that they are communicating with a person in the next booth. This was made more convincing in two ways. The first way was to have a ten second pause after the participant typed in the string with the screen reading "please wait ten seconds while your partner makes their choice". The second way was to have someone in the booth next to them. As participants were told they were not allowed to see their partner until after the experiment this was easy enough. This allowed the participants to hear the movements of another participant and their interaction with the experimenter. This course of action was taken after a trial run of the experiment to ensure the programme was running correctly where there was only an empty booth next door with the light on and most participants were not fooled affecting the validity of the results which were dependant on the belief that communication was taking place. This perception of communication was encouraged by the three alternative meanings that appeared across the top of the screen that the participant believed their partner would select from.

Results:

Due to the small amount of data in my experiments (the reasons for which are discussed in section 5.1 there are only three main measurements of the results.

The first of these is very simple – the number of distinct signals produced in each generation. This is shown as ‘Distinct Signals’ in Table 1. The second measurement is the error of transmission. This is a measurement of how successfully a generation has learnt the data that they were trained on. This was done by calculating the Levenshtein Distance between the string that a participant was trained on (the input) and the string that they produced (their output). The Levenshtein Distance gives us the amount of changes that are needed to get from one word to the next in the smallest number of steps. For example, in generation 2 the red circle with a straight movement went from ‘miki’ to ‘pimiwi’ has a Levenshtein Distance of 3. This is calculated as shown below:

miki → pimiwi

miki → miwi counts as 1 as ‘k’ to ‘w’ is one change

miki → pimiwi counts as another 2 as you have to add two more letters ‘p’ and ‘i’ to the beginning of the word

Altogether this gives a Levenshtein Distance score of 3. This was done for every pair of words for each generation.

This was then normalised to account for the differences of length of the words in the data. This produced a number between 0 and 1. 0 means that the participant did not get a single character of the input right and 1 means that they reproduced the string perfectly. To normalise the data was the Levenshtein distance of each pair was divided by the length of the longer of the two strings that are being compared. The score for each word in a generation are then averaged to give the score for a generation. The break down for each generation’s normalised Levenshtein Distance (nLD) is shown in Table 1 as ‘Transmission Error’. The last of the measurements used in the analysis of the data was to calculate the structure of the language for each generation. To do this a Mantel Test was performed. The distance between all the pairs of meanings was calculated using a Hamming Distance and the distance between all pairs of signals was calculated using a normalised Levenshtein Distance. This leaves us with two lists of distances, one for the meanings and one for the signals. The Pearson’s product-moment correlation is then performed on these lists resulting in data showing us how many similar meanings are

expressed using similar strings. To test if this correlation is significant or otherwise a Monte-Carlo randomisation of the language was carried out 10000 times each where the word forms were shuffled in respect to their meanings and the pair-wise distance correlation for each of the randomisations was recalculated. A z-score was then calculated from this data to allow an indication of how many standard deviations from the mean our results are. If the z-score is larger than 1.96 the score is significant within a 95% confidence level and the language is considered structured. These results are shown as ‘Structure’ in Table 1 below:

Experiment 1	Gen1	Gen2	Gen3	Gen4	Gen5	Gen6	Gen7	Gen8	Gen9	Gen10
Distinct Signals	24	23	19	20	16	16	17	14	12	15
Transmission Error	0.656	0.654	0.431	0.409	0.525	0.11	0.078	0.306	0.219	0.047
Structure (z-score)	0.487	0.45	5.451	2.93	7.185	7.069	8.805	3.501	5.719	9.177

Table 1: A break down of the analysis of each generation. Table shows the number of distinct signals produced for each generation, the measurement of how well each generation learnt the previous generation’s language and the measurement of language structure for each generation.

The results of experiment 1 were disappointing but informative. As seen in Chart 1 the transmission error decreases over the generations as the number of distinct signals decrease as seen in Chart 2.

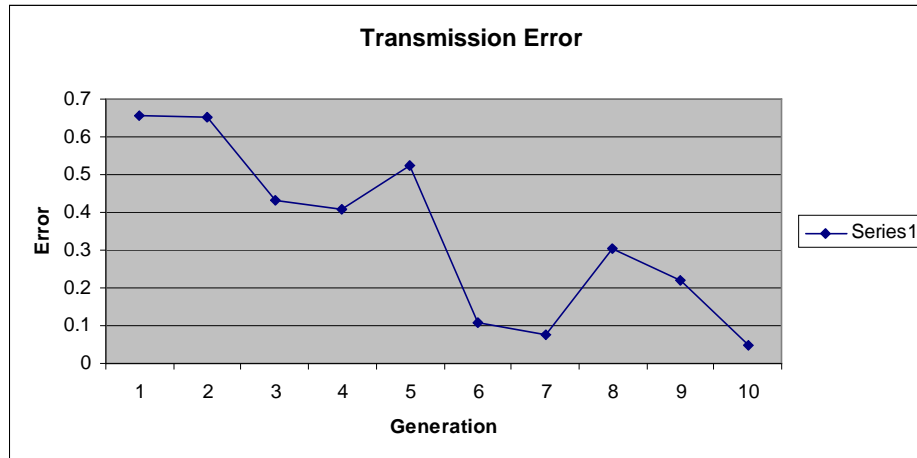


Chart 1: Chart shows the gradual decline in transmission error over 10 generations in experiment one.

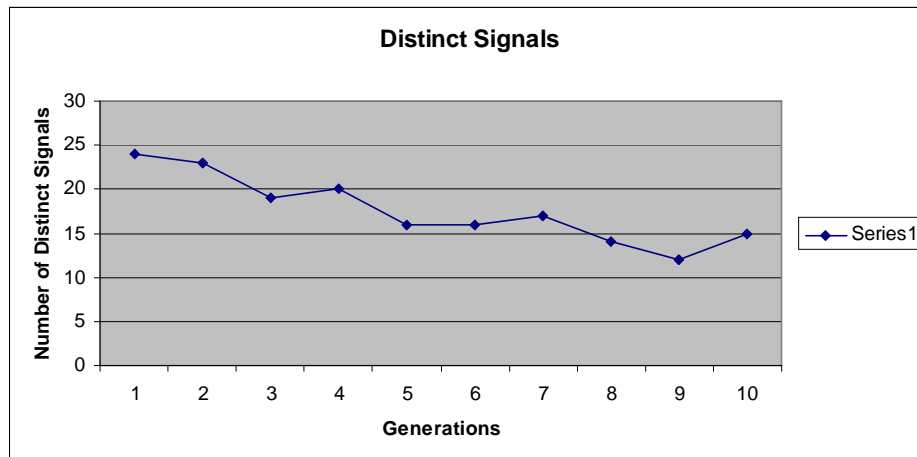


Chart 2: Chart shows the decrease of distinct signals in experiment 1

The distinct signals decrease over time as the transmission process cumulatively introduces homonymy, with more than one meaning being paired with the same string, and therefore ambiguity. Cultural transmission of the language has, under these conditions, used underspecification to make the language more learnable. This is not surprising as you would expect people to get more things right when they had less signals to remember. The structure (chart 3) also increases over the generations as the error decreases. Any number above 1.96 is considered a structured language. The relationship between the structure and degree or error can be seen in generation 8 where there is a

jump in errors and also a sizable decrease in structure. Once the error numbers decrease again in generation 9 the structure increases.

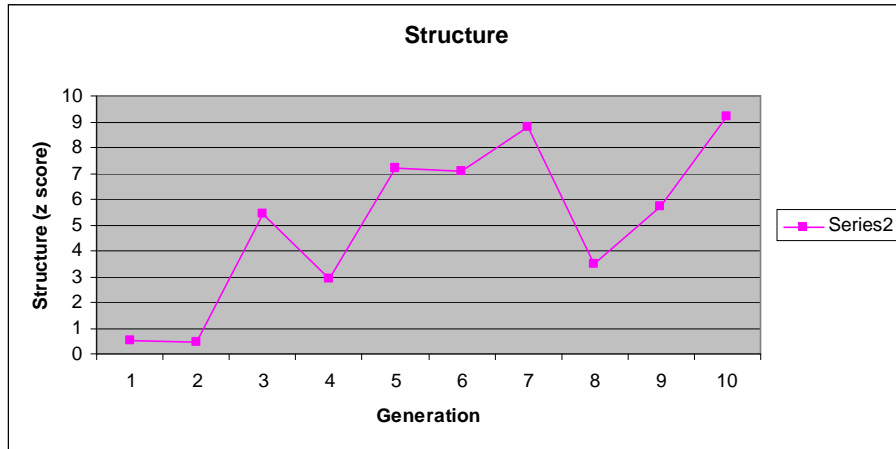


Chart 3: Chart shows the increase in structure as the language adapts to be learnable

That the number of distinctive words and decreasing and the structure is increasing suggests that the language is adapting to become more learnable between each generation – with the exception of generation 8. That structure increased and error decreased despite the participants being exposed to only half the data. The underspecification alone cannot account for participants being able to respond with the correct string even though they have not been exposed to it. Kirby et al. (2008) explain that the only way to learn an unstructured language is by rote and this applies to a randomly underspecified language. As the participants were not exposed to all of the language in my experiments, as with Kirby et al's (2008), rote learning is not possible and cannot explain how participants can get words correct that they were not exposed to. The results of my experiment can only be explained if the underspecification is systematic. This can be seen by the progression of the language throughout the generations. By generation 6 all black meanings are indicated 'mel' (although this changes by generation 8 which is not unexpected considering the rise in transmission error in generation 8 as can be seen in chart 1). By generation 6 all jumping shapes were described by 'hipini' (and stayed that way by the end of the language). By the 10th generation, all straight movements are distinguished by shape e.g. red, blue and black straight squares are all 'gelhini'. See Appendix 1 for a breakdown of all generations in experiment1). Because these generalisations across the language allow participants to

correctly label meanings they have not been trained on. It is these generalisations that, according to Kirby et al (2008: 10683) “directly ensures the stable cultural transmission of the language from generation to generation” despite the input being incomplete. The structure measurements used confirm that the language is getting significantly more structured between each generation (see chart 3) with the exception of generation 8 where the error degree increases and the structure decreases, though both recover again by generation 9. Figure 4 below shows the last generation of Experiment 1.



Figure 4: Generation 10 language

3.3 Discussion

Although this experiment has proven that the language is evolving to become more learnable it is still, like Kirby et al’s (2008) first experiment, doing so by becoming underspecified, informing us that the idea of communication alone is not enough to create a structured but expressive language and that it is maybe not the communicative aspect of communication that created the pressure for an expressive language. A second

experiment was then carried out that would involve real communication and feedback to see if a compositional but expressive language would emerge.

Chapter 4:

Experiment 2

4.1 Methodology

Experiment 2 was very similar to experiment 1 but instead of implied communication real communication took place. Two participants were used in each generation with one producing signals (referred to as the speaker) and the other choosing which meaning that signal corresponded to (referred to as the hearer). Both participants were trained on the same data. Once the hearer had made their choice in the test phase both the speaker and hearer are shown the target meaning, the signal string and the hearer's choice with the corresponding message "wrong. You lose!" or "Correct! You win". There was also a counter displayed next to the message with the total amount of tests that the participants had gotten right throughout the rounds. Again, only the speakers output from the third generation (where all 27 meanings were tested) were used as in the input for the next generation.

4.2 Results

The same three measurements of the data for experiment 1 were carried out for experiment two. However, due to technical problems that shall be discussed in detail in section 5.1 there were not always a full set of 27 signals produced for each generation in experiment 2 so I have provided a percentage of distinct signals as well the number of distinct signal to give a more accurate view of the results.

The results from experiment 2 were far more promising in respect to a structured and expressive language emerging despite the results being rather noisy due to the technical problems (see section 5.1). The error transmission over the span of the experiment decreases as in experiment 1. However, as you can see from the transmission

error (chart 4) and the structure measurement (chart 5) there is an overall decrease in transmission error and an increase in structure.

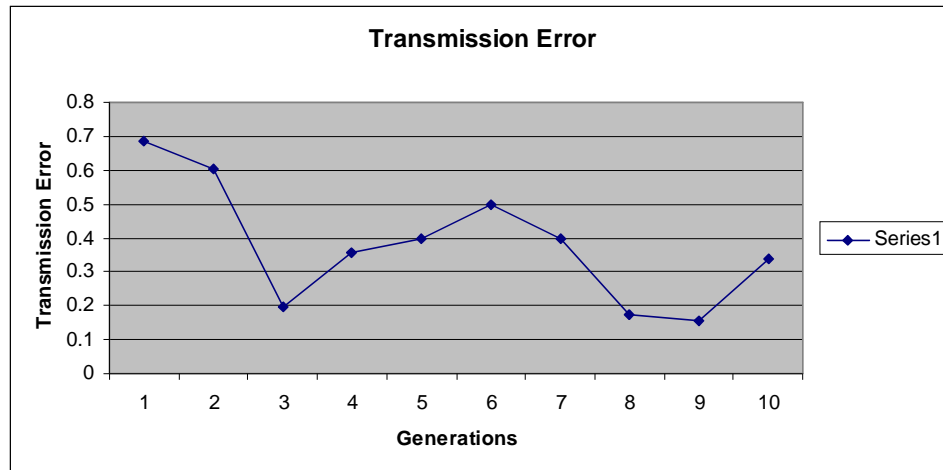


Chart 4: Chart shows the generally decreasing transmission error over the ten generations of experiment 2.

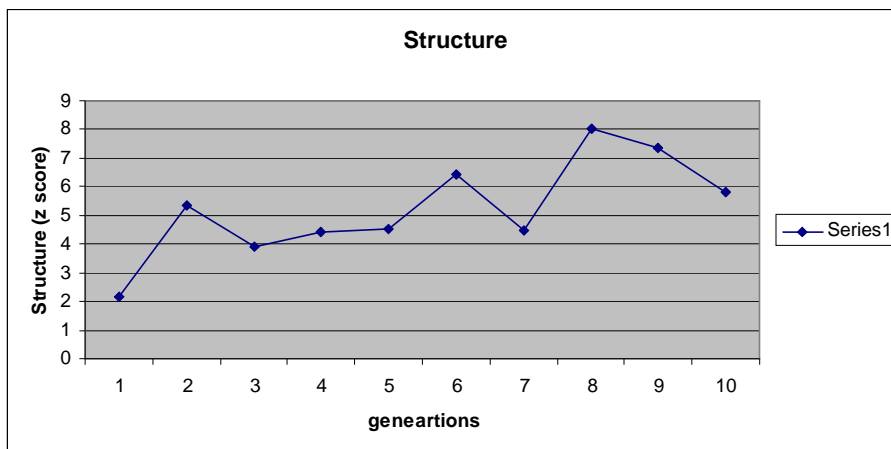


Chart 5 shows the increase in structure of the language as it adapts to be learnable.

EXPERIMENT 2	GEN1	GEN2	GEN3	GEN4	GEN5	GEN6	GEN7	GEN8	GEN9	GEN10
Distinct Signals	22/27	9/22	12/14	10/15	19/19	12/24	13/15	22/22	24/25	25/26
Distinct Signals (Percentage)	74%	50%	86%	67%	100%	50%	87%	100%	96%	96%
Transmission Error	0.684	0.604	0.196	0.356	0.397	0.497	0.398	0.176	0.156	0.337
Structure (z-score)	2.138	5.336	3.915	4.409	4.538	6.451	4.463	8.046	7.368	5.809

Table 2: A break down of the analysis of each generation. The table shows the number of distinct signals produced from the amount that was tested on. It also shows the number of distinct signals as a percentage of the signals that were tested on. The measurement of how well each generation learnt the previous generation's language and the measurement of language structure for each generation.

The charts themselves are rather messy due to the technical problem of not all 27 meanings have been tested on in every generation. The large dip in error transmission (chart 4) at generation 3 is partly due to the small number of meanings being tested (see appendix 2 for a table of what meanings were tested on and produced). These results in lower transmission error as there are less shapes to remember and generalise to. The spike in generation two in structure (chart 5) is due, again, to the small number of shapes produced in the following generation and not that generation 2 is largely more structured (though it is still more structured than the last generation. That it appears in our figures more structured is deceptive as a generation tested on only 14 shapes rather than 27 (as is the case with generation 2) will appear more structured due to the smaller amount alone. However, chart 4 clearly shows the increase of structure between the first and last generations, concluding that the language is, in face, becoming more structured, like experiment 1, as we had hoped. The results from generation 10 for both the error transmission and structure (that are higher and lower respectively) can be explained in the same terms as previously mentioned – as the number of meanings produced in generation 10 (26) was great than generation 9 (25). Chart 6 shows the number of distinct signals produced by each generation by percentage of the number of signals produced by that

generation as giving the actual number of distinctive signals may be deceptive due to the varying numbers of signals produced.

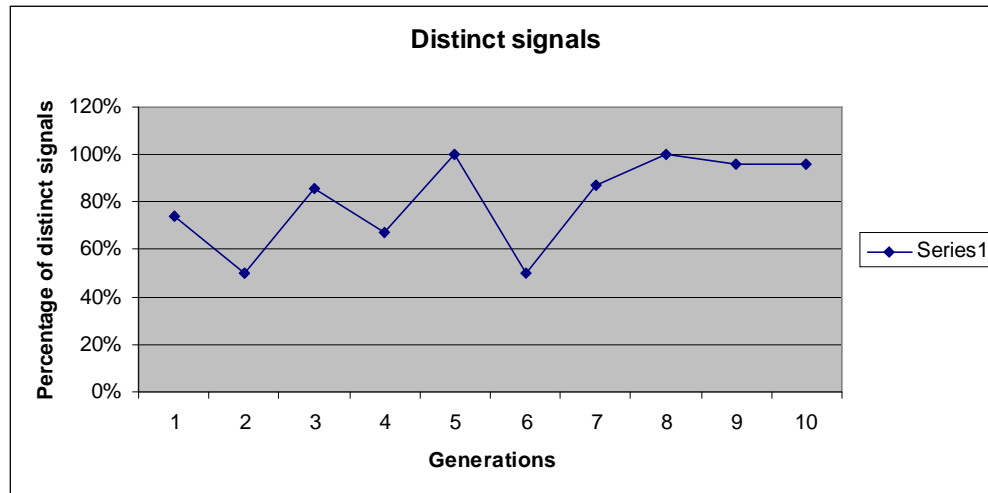


Chart 6: Chart shows the eventual increase in distinct signals as the language adapts to be learnable but expressive.

Overall however, the number of distinct signals is quite high throughout most of the experiment, showing that the language is expressive. Overall, the results of the experiment show, despite the noise, that the language is evolving to become more learnable by becoming structured but is also expressive. Scott-Phillips and Kirby (in press) define a bottle neck not only as limited input but also “transmission noise” (Scott-Phillips and Kirby, in press: 4) so it could be argued that the unfortunate noise during the experiment can be described as adding to the bottleneck. The structure of the language can be seen as the language evolves through the generations. By generation 7 (see appendix 2) ‘t’ means a triangle shape and by generation 2 ‘mehe’ already indicates the jumping movement. By generation 10 this is still the case despite it being somewhat lost in generation 6 (see appendix [insert number] for the full list of productions for each generation). This only serves to strengthen the argument for the power of the pressure of cultural transmission to make languages more learnable by becoming structured. By

generation 10 we have a decent degree of set components for the different features of the meaning space (i.e. the colour, movement or shape). Although it is not as perfect as we would have hoped, with the amount of noise through the generations the degree of compositionality that we have is encouraging. See Figure 5 below for results of generation 10. By generation 7 ‘t’ means triangular and by generation 8 ‘r’ means square. Figure 5 below shows the language for the 10th generation of Experiment 2.

□	bredwedge	rblkwedge	rbluwedge	→
○		bblkikikiwidge	bbluwidge	
△	rredwidge	tblkwidge	tbluwidge	
□	bredikikimehe	rblkikikimehe	rbluikikimehe	~
○		bblkikikimehe	bbluikikimehe	
△		tblkikikimehe		
□	rredikikiwidge	rblkikikiwidge	rbluikikiwidge	↻
○	bredwedge	bblkwidge	bbluikikiwidge	
△	tredikikimehe	tblkikikiwidge	tbluikikiwidge	

Figure 5: Generation 10 of Experiment 2

Although there are signals missing and not all aspects have become stable yet due to the malfunctioning of the programme, the language is structured to a reasonable degree (anything with a z-score is considered structured within a 95% confidence level) and compositional even if the components have not become structured yet. That we can attempt generalise to the missing data is further support of the compositionality and expressivity of this language. The jumping movement has stabilised as ‘mehe’ by generation 8, ‘red’, represents the colour red, ‘blk’ black and ‘blu’ blue. The obvious influence of English can be seen here but otherwise ‘b’ for circles and ‘r’ for square is not a reflection of English.

4.3 Discussion

What these results suggest is I argue, that feedback plays an important role in creating the pressure for languages evolving, via cultural transmission, to become not only structured but to be expressive. Kirby et al (2008) described filtering in their second experiment as artificial but that it was “an analogue of a pressure to be expressive that would come from communicative need in the case of real language transmission”. These results, I argue, suggest this to be the case as by adding communication with feedback an expressive compositional language emerged.

Chapter 5

Discussion of Experiments and Results

5.1 Issues with experiment

For my experiment it was decided that I would try adding communication only in the perceived sense. This was to see if the thought of communication is enough to filter for homonymy. However it was found that although the participant was convinced that they were participating with another person the language still broke down into a structured but undescriptive language as happened in Kirby et al's (2008) first experiment.

In hindsight this is not unexpected as it is not the talking to other people that changes our I-language but our observation of (and interaction with) other people's E-language that helps create our I-language.

As communication alone did not achieve our aim, a second experiment was carried out where real participants received instant feedback on their performance during the experiment. The results of this experiment were more promising with a compositional language emerging. However, the actual results are not as clear cut as I would have hoped due to programme malfunctions which resulted in not every generation being tested on all 27 shapes in the third round of testing. This means that not every meaning went through ten generations of cultural evolution so a meaning may be presented as input for generation 9 may have the same signal attached to it as it did in generation 6, not because generation 7 and 8 kept the same signal but because they were never tested on it did not have a chance to be influenced by the cultural transmission between these generations.

"To err is human, but to really foul things up you need a computer" Paul Ehrlich

As Experiment 1 had similar issues, time restraints resulted in one only chain per experiment. The data from the trial run for Experiment 1 were also not useable as official data due to the malfunctioning programme and participants surmising that there was no second participant in the booth which may have contaminated their data.

5.2 Discussion of Experiment Design and Results

The effects of cultural transmission have proven to be stronger than I could have hoped with a large degree of compositionality emerging despite the noise throughout the generations. Due to time constraints caused by a continuous malfunction in the first programme which caused similar malfunctions as happened in experiment 2, a rerun (or multiple chains) of the second experiment was not possible. However, from the data (see Appendix 2) I argue that we can claim that communication with feedback does filter for homonymy and encourages the emergence of a compositional language that is both structured and expressive.

The important results from these experiments is that we have learned that it is not the communicative aspect that encourages expressivity but feedback. Feedback is the key feature here as participants who played the role of speaker – the ones who typed in the signal – reported (in questioning after the experiment) that they would change their interpretation of the language for the benefit of the hearer based on their experience of the hearer’s interpretation of the language through the feedback after each test. For instance, if the target meaning was a blue triangle with a straight motion and the hearer chose a black triangle with a straight motion, the hearer would usually adapt their naming of the string so that the part that they thought meant ‘blue’ would now mean to them ‘black’. This supported by Whiten et al.’s (2005) finding with chimpanzees and the cultural learning of tasks where they found there was “a conformist bias...as a powerful tendency to discount personal experience in favour of adopting perceived community norms”. (Whiten et al., 2005: 738) It is important to reiterate at this point that the participants are not aware of being tested on things they have not seen. There is also the additional pressure of getting the signal right – which in real life communication terms would be the pressure to be understood by the hearer.

In questioning after the experiment, ‘speakers’ reported that they did in fact pay attention to what the ‘hearer’ chose and that it consciously affected their next attempt at naming e.g. a black shape even though they believed the component part to be one thing, they would adjust for the speaker’s interpretation of the language. This is similar to the situations that arise between native and non-native speakers of a language when the non-native speaker uses non-grammatical phrases, the native speaker is more likely to adopt these non-grammatical utterances or style.

The participants reported after the experiment that by the second round of training (some earlier) that they were specifically looking for patterns in the signals – component parts that referred to shape, colour or movement. The 8th generation of the second experiment were so sure of the pattern that they reported afterwards that, more or less, the first letter indicated the shape, the second and third letters the colour and the rest of the word indicated the movement. For example, the black triangle with a jumping movement was ‘tblkmehe’, with the ‘t’ meaning triangle, ‘blk’ describing the colour and ‘mehe’ describing the movement. The decision to provide the hearer with choices that differed from the target meaning in only one aspect proved to be more important than originally thought. When deciding how many choices to give and which choices to give a few alternatives (e.g. one from the SEEN set, one from the UNSEEN set and one chosen at random) had been considered. The decision on how many choices to provide (four) was linked to the choices that I provided. As I decided on providing additional meanings with only one aspect that was different (colour, shape or movement) from the target meaning four choice meanings were necessary.

It may be the case, however, that a participant playing the part of the hearer could deduce from the four presented shapes which one is the target one if they realised that one of the shapes presented differed from the others in more than one aspect. However, the participants were not aware of the link between the four shapes and none appear to have worked it out.

5.3 Implication of results

The reason why both experiments were carried out was to isolate the effects of communication and feedback respectively to see which was playing the important role.

As people were convinced that communication was actually taking place (this was ascertained through questioning of participants after the experiment) real communication was not necessary for the results of the first experiment.

The two experiments and their results are example of cumulative cultural adaptation of a language without conscious design by the participant. This was done under controlled laboratory conditions. As with previous computational models (Hurford, 2000, Kirby, 2000) as well as previous ILM experiments in humans (Kirby et al., 2008, Line, 2010) my results suggest that a language will evolve through cultural transmission to ensure that it is learnable to be transmitted successfully through a bottleneck caused by the limited exposure of the language for each new generation. The languages adapt to this problem of incomplete input by becoming more structured based on the structure of the meaning space so that the language can generalise to unseen meanings. This adaptation is only necessarily in the interest of learnability and an increase in structure and does not mean that the language will adapt and still maintain its expressivity, “cumulative adaptation does not suggest that the languages necessarily become more functional with respect to communication”. (Kirby and Smith, 2008: 10685).

How do these results relate to the real world and to normal language usage? This is important as the reason behind computational modelling and human iterated language models is to try to understand how language had emerged and why it is as it is and not some other way. For my results to be worthwhile they have to relate to real language usage. Below I will explain how my results are relevant in the real world.

In both my experiments the languages became both structured and learnable via cultural transmission. The homonymy that existed in the first experiment was not by any means random, but was systematically underspecified. Kirby et al (2008) reported that the form of the language from their first experiment was reflective of the regularities in the meaning space used i.e. the colour, shape or movement. In Kirby et al’s (2008) first experiment, participants reported that certain factors of the meaning space were not important to the aliens (as the language they were taught was presented as an alien language) and that is why they were not distinguished by the signal. This is not unlike the responses from my own participants. After a participant took part in the experiment they were asked to explain what they thought they were doing. Three participants reported,

from generation 6 onwards, that they were distinguishing between the shapes and movements. When asked about the colours, one participant said they just ignored it because they could not see how it was distinguished in the strings and the other two said they were not aware that the colour was meant to be included in distinguishing the meanings. That it was the colour that lost distinction in the strings is not surprising as Landau et al. (1988) reports that it is expected by people that words will refer to shape rather than colour. Kirby et al (2008) argues that when becoming learnable by systematic underspecification, a language will lose what is perceived to be the least important distinction.

Systematic underspecification occurs naturally in language use. Kirby et al (2008) gives an example of underspecification in real language use - common nouns. Common nouns that do not refer to specific entities like proper nouns do, but rather to categories e.g. dog, cat, car compared with Honey the dog, Mungo the cat and my dad's MX-5. In this way, the results of experiment one are reflective of language evolving to become more learnable by systematic underspecification.

The system of adaptation adopted by the language in the second experiment is reflective of another naturally occurring adaptation for learnability - compositionality. Compositionality in morphology and syntax is used by our species to allow us to create an expressive language that is learnable and transmittable through the bottlenecks of children's minds. Due to the communication and feedback in the second experiment a compositional and expressive language emerged – allowing participants to describe all features of the meaning space without needing to have been exposed to the meaning and its string before. I could also word this in another way and suggest that the feedback didn't just allow the participants to describe all features of the meaning space but actually caused the pressure for expressivity.

In the first experiment all that the participant was required to do was to reproduce as best as they could the input they received in the training phase in the hope that the participant they believed they were working with (the 'fake' participant) would pick the correct meaning. However, as there was no feedback in the first experiment the participant did not know anything about the fake partner's internal representation of the language (I-language) and therefore could not adjust their output (E-language)

accordingly. In the second experiment however, the participant taking on the role of the ‘speaker’ was given feedback on the ‘hearer’s interpretation of the language and the speaker’s interpretation of the language. This created a pressure for the speaker to strive to be understood by the hearer and to do this the speaker had to disambiguate all aspects (the shape, movement and colour) of the meaning space. To carry on to the next generation via cultural transmission and through the bottleneck the language must therefore be not only learnable but expressive.

The evolution of compositionality in both these experiments (underspecified or otherwise) supports that cultural transmission encourages languages to adapt to deal with the pressures of a transmission bottleneck (such as limited and incomplete input) that is in place between the speaker of a language and the learner of a language. As both experiments started off with the same original ambiguous and random language and produced two very different languages, the languages themselves were not a result of the participants’ native and only language – English. Although the second experiment did have elements that were obviously influenced by English (such as ‘t’ for triangle and ‘red’ for red) most of the components within the language were not related to English and if their native language had had such a major role in the language formation we would not expect to find two very different systems in use as we found between our experiments.

I would argue that the forms of feedback provided in the interactive condition of Walker et al.’s ‘pictionary’ experiment are playing a large role in the success of the interactive condition’s dyads, more so than Walker et al. (2009) acknowledge. If this is the case then I would claim that Walker et al.’s (2009) results support my findings of the importance of feedback in the evolution of language. I would also argue that Garrod et al.’s (2007) and Line’s (2010) results support my findings as it is the interaction in their studies that they suggest results in structured and expressive languages. However, I argue that ‘interaction’ and ‘feedback’ are, in these circumstances, interchangeable labels as my results suggest that the communicative aspect of interaction does not produce a pressure for expressivity but feedback does. My results are however, collected from a vertical transmission iterated learning model and not a horizontal one such as Line (2010) but I would still argue that

Chapter 6:

Conclusion

The aim of this study was to attempt to isolate the effect of communication and feedback respectively, to investigate the effect of each on language evolution and if either or both was enough to create a pressure for a language that adapted to be learnable by being both structured but also expressive. This was an extension of Kirby et al's (2008) study that provided a framework for investigating the cumulative evolution of language without intentional design on behalf of the participants. Kirby et al (2008) were able to produce a structured and expressive language in their experiment but only after they artificially filtered for homonymy. My hypothesis was that communication and/or feedback would act as a natural filter for underspecification.

For my first experiment communication was added to Kirby et al's (2008) framework but the language degenerated to a structured but underspecified language. The second experiment introduced feedback to the framework of experiment 1 and resulted in a structured and expressive language. This suggests that feedback plays a crucial role in creating a pressure for expressivity with participants playing the role of speaker reporting that they would adapt their input based on the error of the hearer to increase their chances of being understood. This is in keeping with previous research on cultural transmission including that of chimpanzees (Whiten et al, 2005) where an individual is more likely to adapt to a cultural norm than their own initial interpretation of a task.

The findings of this study add to the growing literature on language evolution in the laboratory and supports previous findings on the importance of feedback in developing structured and expressive languages (Garrod et al, 2007, Walker et al, 2009,

Line, 2010). The field of language evolution has, in recent years, come on leaps and bounds with regard to understanding the processes that may contribute to the evolution and development of languages and its features such as syntax and why language appears as it does and not in other ways. However, no matter how much we advance in our experimental techniques and methodologies we can only experiment on humans with an already evolved language faculty and cannot directly relate our findings to language as spoken by the original speakers of language. This is not, however, the focus of language evolutionists, but rather the research conducted in this field enables the investigation of “the precise nature of various phenomena (both biological and, especially, cultural) that underpin the emergence of shared symbolic communication systems” (Scott-Phillips and Kirby, in press).

Appendix 1 and 2:

Language Families of Experiments 1 & 2

Appendix 3:




























Shape Gen 0 Gen 1 Gen 2 Gen 3 Gen 4 Gen 5 Gen 6 Gen 7 Gen 8 Gen 9 Gen 10



















Instructions










Appendix 4:

Shapes used for Trail Run

The first table is the languages produced for Experiment 1. The second table is the language family for Experiment 2. The stars show where a meaning was not tested on. The third appendix is a copy of the instructions that participants received for both experiments. The fourth appendix is a copy of the shapes used in the trial experiment.

	mahekuki	pihemiwi	limpini	melkinihipi	maelikihipi	melhiki	melapiki	melahiki	melahini	gelihiki	gelihiki
	kikumi	winihekuge	wikipiniki	meikleini	wipimpihiki	melihipi	melihipi	melahipi	gelhipini	gelihipini	gelihipini
	gepinini	pimpini	pimiwi	pimiwi	pampihini	melapiki	melapiki	melapiki	melahiki	gelihini	gelihini
	nipi	wikihemiwi	wikipelgimi	wikimelhipi	wikigelipiki	melahiki	melapiki	melipiki	gelhiki	gelhiki	gelhiki
	miwimi	wikipinike	wikigilke	pimphipi	wikimelhipi	melahipi	melahipi	melihipi	gelahipini	gelhipini	gelhipini
	wige	wikikuge	pimpini	pimpini	pimpihiki	melapiki	melapiki	melipiki	gelihiki	gelhini	gelhini
	pinipi	pinipi	kelgiki	wikigelhipi	wikimelhipi	melihiki	melahiki	melihiki	elahiki	elihini	elihiki
	mihe	kepihekuge	wikipempiwi	wikimelhipi	wikimelihiki	melihipi	melihipi	melihipi	gelhipini	elihipini	elihipini
	pikuhemi	pinipi	pimpini	pimini	pimpihiki	melipiki	melipiki	melipiki	gelihiki	elihini	elihini
	wigemi	miwihekipe	melhini	melhiniki	wikigelihiki	gelahiki	gelahiki	gelahiki	gelihini	gelahiki	gelehiki
	pimikihe	pihemiwi	wikimelhini	gelhipini	wikigelipihipi	gelihipi	gelahipi	gelahipi	gelahipini	gelihipini	gelehipini
	wikima	pimhemiwi	pimipi	pimiwi	pimini	gelapiki	gelipiki	gelapiki	elahiki	lihini	gelehini
	miniki	pihemike	wikigehlini	gelhipiki	wikigelihipi	gelahiki	gelahiki	gelihiki	gelhiki	gelhiki	gelhiki
	kunige	mehikelige	wikipontini	gelikhipi	wikigelipihipi	gelihiki	gelahipi	gelihipi	gelhipini	gelhipini	gelhipini
	winige	mihelige	pemkelgi	pimpini	wikipimpiki	gelipiki	gelapiki	gelipiki	elahiki	gelhiki	gelhini
	gepihemi	pihiekuge	melhangini	pimhipiki	wikigelihiki	gelihipi	gelihiki	gelihiki	elahiki	elihiki	elihiki
	hema	pehekihike	wikipimipi	meliki	wikigelipiki	gelipikihipi	gelihipi	gelihipi	elahiki	elihipini	elihipini
	kinimage	pinipilige	pimpini	pimini	wikipimini	gelipiki	gelipiki	gelipiki	elhiki	elihiki	elihini
	kinimapi	pimhewike	wikipelkiki	gaelikihipi	gaelikihipi	elihipi	elipiki	elapiki	elahini	gelahiki	gelahiki
	miwiniku	pimkemiwi	wikipemike	melhipi	wikelipihiki	elihipi	elihipi	elahipi	gelhipini	gelahipini	gelahipini
	miki	pimiwi	pempini	pimpiwi	pimpini	elipiki	elapiki	elapiki	elahiki	gelihiki	gelahini
	wikuki	pihekige	kelgehlgie	wkikmelhiipi	wikielihipi	elihipi	elapiki	elahiki	gelihiki	gelhiki	gelhiki
	nihepi	wikpiheke	wikimelgini	wikielhipi	wikielhipi	gelihipi	elahipi	elahipi	gelhipini	gelhipini	gelhipini
	nipikuge	pekuhelige	pimipi	pimpini	wikielipiki	elipiki	elapiki	elipiki	elhipini	gelhini	gelhini
	kimaki	pehekekuge	wikimelhipi	wikimelhipi	gaeliki	elihiki	elihiki	elihiki	glahini	elihiki	elihiki
	wimaku	pehikelige	wikipempini	wikigelhipi	wikigelihiki	elihipi	elihipi	elahipi	gelhipini	elihipini	elihipini
	kihemiwi	wikikuge	pimiwi	pimiwi	wikielhipi	elipiki	elapiki	elipiki	melhiki	elihini	elihini

Shape	Gen 0	Gen 1	Gen 2	Gen 3	Gen 4	Gen 5	Gen 6	Gen 7	Gen 8	Gen 9	Gen 10
	mahekuki	kiniwige	*	pekiginmi	*	kikiginmi	bkkikiwidge	*	bblkwedge	bblkwedge	bblkwidge
	kikumi	mehe	mehekuge	mehekuge	kikumehe	blmehe	bkikimehe	bblkmehe	bblkmehe	bblkmehe	bblkikikimehe
	gepinini	pekiginmi	kigini	*	kigimi	bkugini	bkkikiwidge	*	*	brikikiwidge	bblkikikiwidge
	nipi	wehimini	wikikuge	kikwige	kikwige	bkukuwige	bkkikiwidge	blblkwidge	rblkwidge	rikikiwedge	rblkikikiwidge
	miwimi	mehkukge	kikumehe	kikumehe	*	bkukumehe	bkkikimehe	brecmehe	rblkmehe	rikikimehe	rblkikikimehe
	wige	wige	kimini	kikimi	kikimi	bkukugini	bkikiwidge	blurecwidge	rtikiwidge	rikikiwidge	rblkwedge
	pinipi	kiniwige	kikuge	wigiwige	pikiwige	rpikiwige	kikwidge	tblkwidge	tblkwedge	tblkwedge	tblkikikiwidge
	mihe	mehe	*	*	*	*	*	tblkmehe	tblkmehe	tblkmehe	tblkikikimehe
	pikuhemi	wigini	wigini	wigini	kugimi	*	bktikiwidge	ttikiwidge	tblktikiwedge	tblkikiwidge	tblkwidge
	wigemi	wekukge	kikuge	*	kikmni	blkikiginmi	bikiwidge	bbluwidge	bbluwedge	bbluwidge	bbluikikiwedge
	pimikihe	mekugige	mehe	*	*	*	bktikimehe	bblumehe	bblumehe	bblumehe	bbluikikimehe
	wikima	gekukge	*	kugimi	*	bwigimi	bkikiwidge	*	*	bbluwidge	bbluwidge
	miniki	wekukge	*	kikiwige	*	*	bkikiwidge	*	rblutikiwedge	rikikibluwedge	rbluikikiwidge
	kunige	mehekuge	*	*	*	blkukumehe	bkikimehe	*	rblumehe	rblumehe	rbluikikimehe
	winige	kukge	kimini	*	*	blkukugini	bkikiwidge	*	*	*	rbluwedge
	gepihemi	wehikukge	kikuge	*	*	blpikiwige	btikiwidge	tbluwidge	tbluwidge	tbluwedge	tbluikikiwidge
	hema	mehekuge	kikumehe	*	*	*	*	*	tblumehe	tblumehe	tbluikikimehe
	kinimage	wukge	wigini	*	*	wigimi	bikiwidge	*	tblutikiwedge	tbluwidge	tbluwedge

	kinimapi	kikikuge	pekiginmi	pekiginmi	pikikwige	rkikiwige	kikiwidge	bredwidge	bredwedge	bredwedge	bredwedge
	miwiniku	kimige	mehe	mehe	kikumehe	pikimehe	kikimehe	bredmehe	bredmehe	bredmehe	bredikikimehe
	miki	gekige	kigini	*	*	kugini	kikiwidge	*	*	*	*
	wikuki	wekikikuge	kikuge	kikiwige	kikiwige	rkukuwige	kikiwidge	*	rredtikiwedge	rrikikiwedge	rredikikiwidge
	nihepi	kikumehe	kikumehe	*	kikumehe	*	kikimehe	rredmehe	rredmehe	kikimehe	rredikikimehe
	nipikuge	kikuge	kimini	kimiginmi	kikimni	rkukugini	kikiwidge	*	*	bkikiwidge	bredwedge
	kimaki	kinimi	wikukuge	*	pikiwige	*	tikiwidge	*	tredwidge	tredwedge	tredikikimehe
	wimaku	mikikuge	mehekuge	*	kikumehe	*	*	tblumehe	tredmehe	tredmehe	rredwidge
	kihemiwi	gekukge	kigini	kigini	kikimi	rwigimi	tikiwidge	tredwidge	tredtikiwedge	tredwedge	tredikikiwidge

Appendix 3

Welcome!

You are about to embark on a crash course on an alien language
consisting of images and their related names.

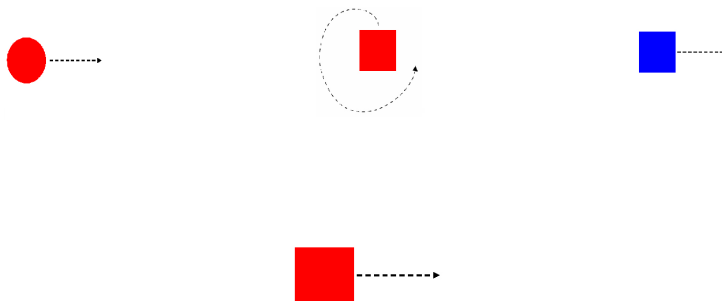
Both you and your partner in the next booth will see each image twice along with the
name of the image:



You will then be shown each of the images that you have been trained on at a time and
are asked to name the image.

Your partner will be shown what you typed and will choose one image from a choice of
4. They have 10 seconds in which to do this.

To help you out you will be shown the 3 other images that your partner will see at the top
of your screen as follows:

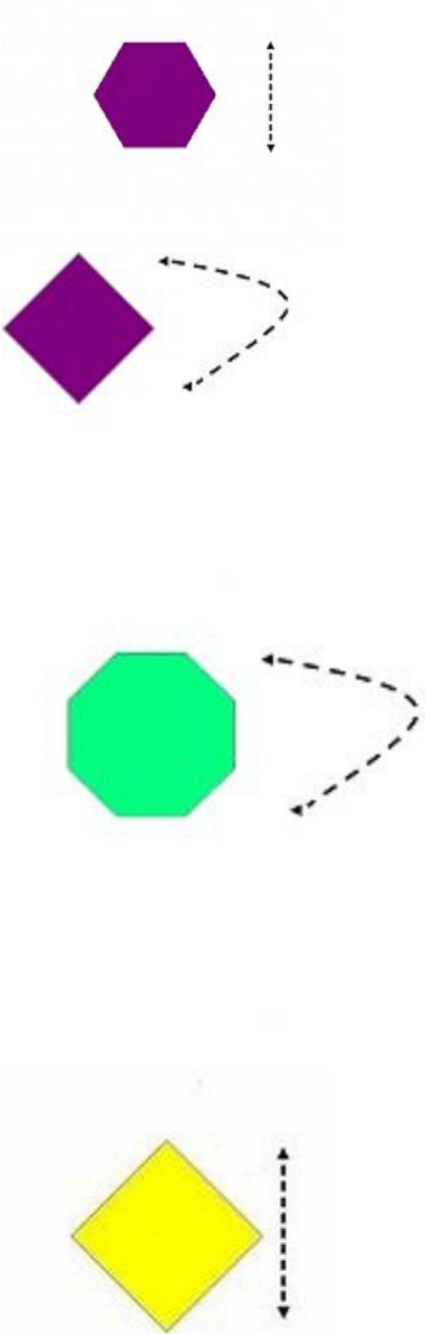


DO NOT WORRY IF YOU HAVE NOT COMPLETELY MASTERED THE
LANGUAGE YET, just try your best to communicate the correct image to your partner.

Please always give an answer.

If you have any questions at any time don't be shy - ask the experimenter.

Appendix 4



Momogona

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